

THE OPERA EXPERIMENT

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Abstract

The physics motivations and the detector design of the long baseline OPERA experiment are discussed; OPERA is a hybrid detector made of several types of electronic subdetectors, 2 magnets and lead/nuclear emulsions “brick” walls. It is located in the Gran Sasso underground lab, 732 km from CERN, on the CNGS neutrino beam. A summary of the performances and of the physics plans are presented.

1 Introduction

Neutrino physics has opened new windows into phenomena beyond the Standard Model of particle physics. Long baseline neutrino experiments may allow further insight into neutrino physics. The CERN to Gran Sasso neutrino beam (CNGS) is one of these projects [1], and one of the main experiments is OPERA [2], designed to search for the $\nu_\mu \longleftrightarrow \nu_\tau$ oscillations in the parameter region indicated by the MACRO [3], SuperKamiokande [4] and Soudan2 [5] atmospheric neutrino results [6], recently confirmed by the K2K [7] and MINOS [8] experiments. The main goal of OPERA is to find the ν_τ appearance by direct detection of the τ lepton from ν_τ CC interactions. One may also search for the subleading $\nu_\mu \longleftrightarrow \nu_e$ oscillations and make a variety of observations with or without the beam using the electronic subdetectors.

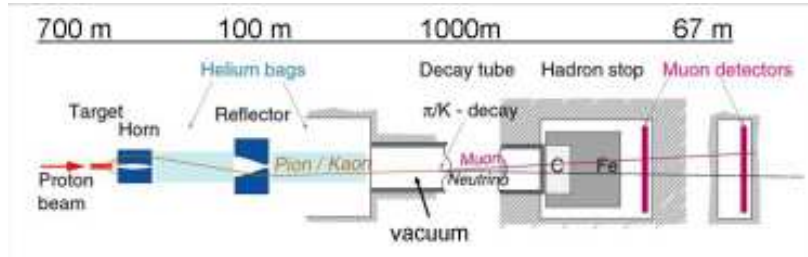


Figure 1: The main components of the CNGS neutrino beam.

Assuming a beam intensity of $4.5 \cdot 10^{19}$ pot/year and a five year run, 31000 neutrino events (CC + NC) are expected in an average target mass of 1.6 kt. 95 (214) ν_τ CC interactions are expected for $\Delta m^2 = 2 \cdot 10^{-3} \text{ eV}^2$ (for $\Delta m^2 = 3 \cdot 10^{-3} \text{ eV}^2$). The detection of the ν_τ 's will be made via the charged τ lepton produced in ν_τ CC interactions, and its decay products.

The τ decays can be classified as muonic (BR 18%), electronic (BR 18%) and hadronic (BR 64%). To observe the decays, a spatial resolution of $\sim 1 \mu\text{m}$ is necessary; this resolution is obtained in emulsion sheets interspersed with thin lead target plates. This technique, the Emulsion Cloud Chamber (ECC), was started in the τ search experiment [9].

The basic target module is a “brick”, consisting of a sequence of 56 lead plates (1 mm thick) and 57 emulsion layers. A brick has a size of $10.2 \times 12.7 \text{ cm}^2$, a depth of 7.5 cm (10 radiation lengths) and a weight of 8.3 kg. Two additional emulsion sheets, the *changeable sheets*, are glued on its downstream face. The bricks are arranged in walls. Within a brick, the achieved spatial resolution is $< 1 \mu\text{m}$ and the angular resolution is 2 mrad. These values allow the reconstruction of the ν interaction vertex and of the τ decay topology. To provide a ν interaction trigger and to identify the brick in which the interaction took place, the brick walls are complemented by a target tracker and a muon spectrometer. The target tracker consists of highly segmented scintillator planes inserted between the brick walls; the magnetic spectrometer measures the muon momentum and identifies the sign of the charges. Combining the signals left in the electronic detectors, the brick containing the ν interaction vertex can be determined with a global efficiency of $\sim 9\%$. The brick is extracted and its changeable sheets are developed and scanned using fast automatic microscopes. If the presence of tracks from an interaction is confirmed, all the emulsion sheets of the brick are developed and sent to the scanning labs for further analysis.

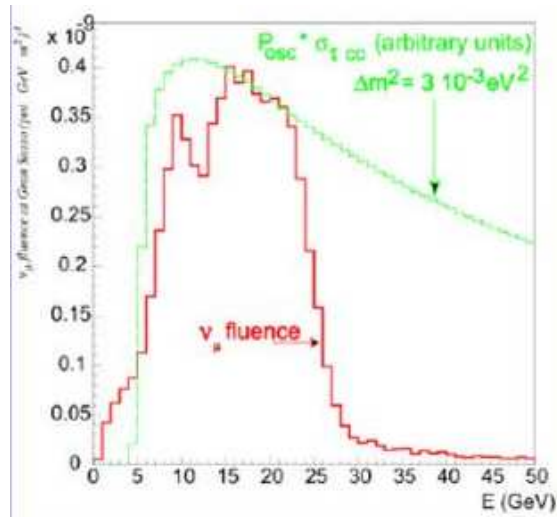


Figure 2: Spectrum of the CNGS ν_μ beam at Gran Sasso.

2 The CNGS neutrino beam

Fig. 1 shows the main components of the ν_μ beam at CERN [1]. The CNGS beam is optimised for a maximum number of CC ν_τ interactions at Gran Sasso (732 km from CERN). The energy distribution at Gran Sasso is shown in Fig. 2: the primary p energy is 400 GeV, the mean ν_μ beam energy is 17 GeV, the $\bar{\nu}_\mu$ contamination is $\sim 2\%$, the ν_e ($\bar{\nu}_e$) is $< 1\%$ and the number of ν_τ is negligible. The L/E_ν ratio is 43 km/GeV. Civil engineering is completed, all beam parts are installed and commissioning is being made; the first low intensity beam is expected at GS in August 2006.

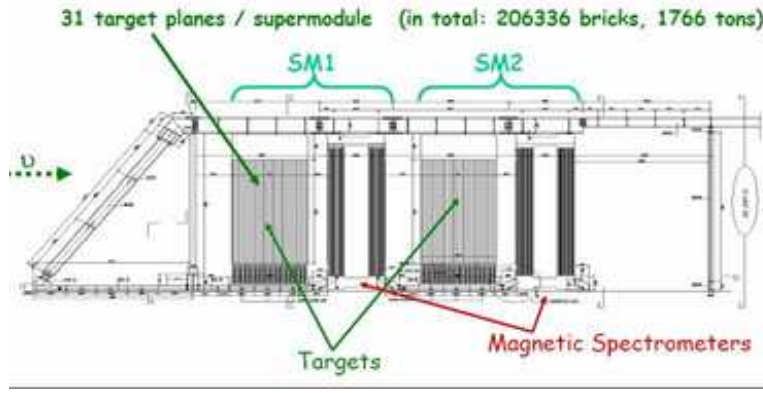


Figure 3: Layout of the OPERA detector.

3 The OPERA detector

The OPERA detector, Fig. 3, is made of two identical super-modules, each consisting of a target section with 31 target planes followed by a muon spectrometer. With 206000 bricks, the initial target mass is 1.8 kt.

Electronic subdetectors. The first subdetector is an *anticoincidence wall* to better separate muon events coming from interactions in OPERA and in the material before.

The *target tracker* is made of 32000 scintillator strips, each 7 m long and of 25 mm×15 mm cross section (7000 m² area). Along the strip, a wavelength shifting fibre of 1 mm diameter transmits the light signals to both ends. The readout is done by 1000 64 channel HAMAMATSU PMTs. The target of the first super-module was installed in November 2005, the second in June 2006. A brick wall position accuracy is better than 1 mm.

The *muon spectrometer* consists of 2 iron magnets instrumented with *Resistive Plate Chambers* (RPC) and *drift tubes*. Each magnet is an 8 × 8 m² dipole with a field of 1.55 T in the upward direction on one side and in the downward direction on the other side. This allows to measure the momentum twice, reducing the error by $\sqrt{2}$. A magnet consists of twelve 5 cm thick iron slabs, alternated with RPC planes. In the magnetic field a muon is tracked, identified and its momentum is measured.

The *precision tracker* [10] measures the muon track coordinates in the horizontal plane. It is made of 12 drift tube planes, each covering an area of 8 × 8 m²; they are placed in front and behind each magnet and between the two magnets. Each drift tube is 8 m long and has an outer diameter of 38 mm. The efficiency of the muon identification, the accuracy of the momentum measurement and sign determination are increased; the charge misidentification should be 0.1 ÷ 0.3%. This minimises the background from charmed particles produced in ν_μ interactions. The muon spectrometer allows a momentum resolution $\Delta p/p \leq 0.25$ for muon momenta < 25 GeV/c. To reduce the number of “ghost tracks” two planes of *glass RPC’s* (XPC’s), consisting of two 45° crossed planes, are installed in front of the magnets.

The construction status in July 2006 is shown in Fig. 4. The brick supporting structure, the tracker planes, the XPC’s and three of the high precision tracker planes of the first supermodule are installed. The magnets, including all RPC’s and the mechanical structure are completed.

To handle the data flow a new DAQ system was developed. It uses a Gigabit network

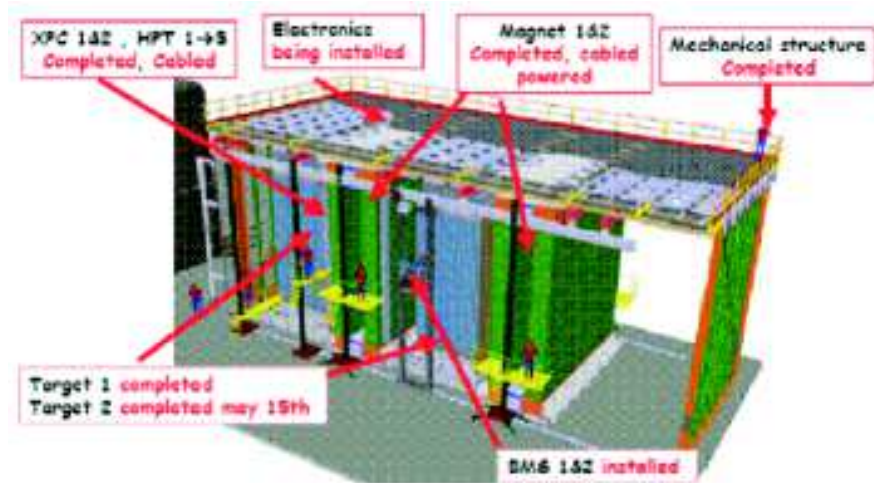


Figure 4: Status of detector installation (July 2006).

consisting of 1200 nodes. To match the data of the different subdetectors an event time stamp is delivered by a clock using the Global Positioning System (GPS). The DAQ uses a system which contains the CPU, the memory, the clock receiver for the time stamp and the ethernet connections to the other components. The components of the DAQ system are under test.

The commissioning of each subdetector is underway. The final commissioning will be made with the CNGS at reduced intensity in August 2006.

Nuclear emulsions and their scanning. The production of the bricks is made by the *Brick Assembling Machine* (BAM). It consists of robots for the mechanical packing of the bricks. In total 23 million lead and emulsion layers are needed to make the bricks. The final system is now installed in the Gran Sasso lab and its production speed is ~ 2 bricks per minute.

The bricks are handled by the *Brick Manipulator System* (BMS), made of two robots, each operating at one side of the detector; one robot consists of a drum for brick transfer and a brick storage carousel. An arm is used to insert the bricks. The extraction of a brick, in the region indicated by the electronic detectors, is done by a vacuum sucker. The first BMS robot was installed in 2005 and the whole system is now being commissioned.

A fast automated scanning system is needed to cope with the daily analysis of a large number of emulsion sheets. The minimum required scanning speed is $\sim 20 \text{ cm}^2/\text{h}$ per emulsion layer ($44 \mu\text{m}$ thick). It corresponds to an increase in speed of at least one order of magnitude with respect to past systems [11, 12]. For this purpose OPERA developed the *European Scanning System* (ESS) [13] and the *S-UTS* in Japan [14].

The main components of the ESS microscope are shown in Fig. 5 left: (i) a high quality, rigid and vibration-free support table; (ii) a motor driven scanning stage for horizontal (XY) motion; (iii) a granite arm; (iv) a motor driven stage mounted vertically (Z) on the granite arm for focusing; (v) optics; (vi) digital camera for image grabbing mounted on the vertical stage and connected with a vision processor; (vii) an illumination system located below the scanning table. The emulsion sheet is placed on a glass plate (emulsion holder) and its flatness is guaranteed by a vacuum system.

By adjusting the focal plane of the objective, the $44 \mu\text{m}$ emulsion thickness is spanned

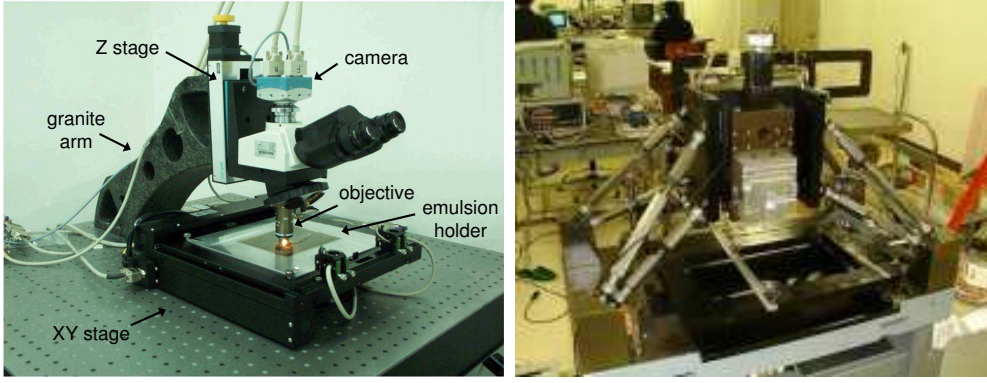


Figure 5: Photograph of one of the ESS microscopes (left) and of the S-UTS (right).

and 16 tomographic images of each field of view, taken at equally spaced depth levels, are obtained. The images are digitized, converted into a grey scale of 256 levels, sent to a vision processor board and analyzed to recognize sequences of aligned grains. Some of these are track grains; others are spurious grains (*fog*) not associated to particle tracks. The three-dimensional structure of a track in an emulsion layer (*microtrack*) is reconstructed by combining clusters belonging to images at different levels. Each microtrack pair is connected across the plastic base to form the *base track*. A set of base tracks forms a *volume track*. The ESS is based on the use of commercial hardware components. The software used for data taking and track reconstruction has a modular structure, providing the flexibility needed to upgrade the system following the technological progress.

The Japanese S-UTS system, Fig. 5 right, is based on hardware designed and made in Nagoya; the software system is mounted in specially designed electronic boards.

4 Physics performances. Conclusions

The detection efficiency of tau decays was studied by MonteCarlo simulations. One distinguishes two cases: (i) “short” decays: the tau decays in the same lead plate where it is produced; the signature is a non-zero impact parameter of the decay products with respect to the primary vertex, which can be determined for multi-prong deep inelastic scatterings (DIS), Fig. 6. (ii) “long” decays: the tau is measured directly and the kink angle of the charged decays accurately determined for DIS and quasi elastic (QE) neutrino interactions.

The first run is scheduled for the second half of 2006. After the commissioning of the CNGS beam and of the OPERA electronic detectors with a low intensity beam, there will be a normal intensity run.

The interactions in the bricks allow to check the analysis procedure, the vertex finding efficiencies and the beam induced background. The expected number of τ events, for a beam intensity of $4.5 \cdot 10^{19}$ pot/year, is 11 (16) events for $\Delta m^2 = 2.4 \cdot 10^{-3} \text{ eV}^2$ (for $\Delta m^2 = 3 \cdot 10^{-3} \text{ eV}^2$). The background is expected to be < 1 . It is hoped that one may improve the selection by $\sim 30\%$ and that the beam may be increased by a factor of 1.5. One should be able to achieve the discovery potential in few years.

We shall also search for $\nu_\mu \longleftrightarrow \nu_e$ oscillations. In case no ν_e is observed and assuming $\Delta m^2 = 2.5 \cdot 10^{-3} \text{ eV}^2$, OPERA shall set a limit $\sin^2 2\theta_{13} < 0.06$ (90% C.L.) [15].

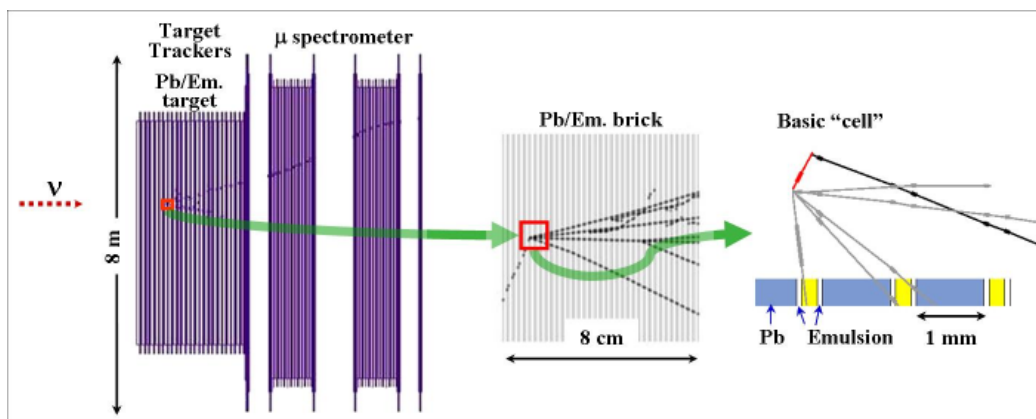


Figure 6: Sketch of one supermodule and of one event in the emulsions.

Several byproducts should be obtained with the electronic detectors.

5 Acknowledgements

We would like to acknowledge the cooperation of all the members of the OPERA Collaboration.

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